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USE OF ERTS DATA FOR MAPPING ARCTIC SEA ICE

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July 1973

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Prepared for
GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland 20771

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16. Abstract

The purpose of this investigation is to evaluate the application of ERTS data for detecting and mapping Arctic sea ice. The specific objectives are to determine the spectral bands most suitable for detecting ice, to measure the scale and types of ice features that can be detected, and to develop interpretive techniques for differentiating ice from clouds and for mapping ice concentrations. The results of the analysis of the data collected during the spring of this year demonstrate that ERTS imagery has a high potential for monitoring arctic sea ice conditions during the time of maximum ice extent and the beginning of the ice-breakup season. In the eastern Beaufort Sea area, the combination of ERTS orbital overlap and a high incidence of cloud-free conditions during the spring assures a high frequency of repetitive satellite coverage. With this repetitive coverage, the deformation and movement of ice features can be mapped throughout the spring season. In the Bering Sea, ice conditions reported by aircraft observation are in close agreement with those mapped from ERTS imagery.

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PREFACE

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The results of the analysis of data collected during the spring of this year demonstrate that ERTS imagery has a high potential for monitoring arctic sea ice conditions during the time of maximum ice extent and the beginning of the ice-breakup season. In the eastern Beaufort Sea area, the combination of ERTS orbital overlap and a high incidence of cloud-free conditions during the spring assures a high frequency of repetitive satellite coverage. With this repetitive coverage, the deformation and movement of ice features can be mapped throughout the early April to late June period.

Ice features that can be identified in the ERTS imagery include the following: the development of fractures leading to the formation of distinct ice floes; the growth and deterioration of leads; evidence of shearing movements of ice masses; the formation of new grey ice within leads; the distinction between grey, grey-white, and older forms of ice; and the deterioration of the ice surface evidenced by the formation of puddles, thaw holes, and drainage patterns. Data from ERTS passes crossing the Bering Sea in early March have been correlated with ice observations collected in the Bering Sea Experiment (BESEX). On two flights of the NASA CV-990 aircraft, the ice conditions in the vicinity of St. Lawrence Island reported by the onboard observer are in remarkably close agreement with the ice conditions mapped from the corresponding ERTS imagery.

1. INTRODUCTION

1.1 Purpose and Objectives

The purpose of this investigation is to evaluate the application of ERTS data for detecting and mapping arctic sea ice. The specific objectives are to determine the spectral bands most suitable for detecting ice, to measure the scale and types of ice features that can be detected, and to develop interpretive techniques for differentiating ice from clouds and for mapping ice concentrations. Standard aerial survey ice charts are being used as a primary source of correlative data to determine the reliability with which ice boundaries and concentrations can be mapped in comparison with other sources of ice observations. The ERTS data are being analyzed mainly for three Arctic areas: the eastern Beaufort Sea, Baffin Bay, and the Greenland Sea.

Because of the inaccesibility of the polar regions, ice survey, which is required for both economic and scientific purposes, is by its very nature a problem that can benefit from space technology. The results of this study will lead eventually to the operational use of future satellite data and, thus, to a more cost-effective means for ice survey.

1.2 Summary of Work Performed During Reporting Period

During the period of performance since the previous progress report (Type I report, 24 May 1973), the analysis of the ERTS data sample from this spring season has continued. Nearly all of the data that have been collected since late March are for the eastern Beaufort Sea area. Following the initial review of these data, mosaics comprising several scenes have been prepared for selected passes. Certain ice features which extend well beyond a single ERTS scene, can be mapped in their entirety from the mosaics. In general, the passes selected for analysis are those which provide repetitive coverage over the same area permitting temporal changes in ice features to be mapped.

The analysis of ERTS imagery covering the area of the Bering Sea Experiment (BESEX) has also been initiated. In the imagery on 6 and 7 March, St. Lawrence Island can be identified as being cloud-free, although

considerable cloudiness covers the ice farther to the south. Corresponding aircraft photography from the NASA CV-990 flights has been requested for the cloud-free areas. It appears that the photography from one flight segment on 7 March should be especially useful for comparison with the ERTS data from the same day.

Aerial survey ice charts covering parts of the easternmost Beaufort Sea have been received from the Canadian Ice Forecasting Central for three dates. Similar data from a Navy ice reconnaissance flight along the northern coast of Alaska in early July will also be sent as soon as the maps are available.

2. MAIN TEXT

2.1 ERTS Data Sample

Data from more than 100 ERTS passes over the Arctic during the past spring season have been received. Nearly all of these passes are for the eastern Beaufort Sea area; only two passes cross the Greenland Sea and 13 cross Baffin Bay. In addition to the above standing-order data, scenes from the four passes crossing the Bering Sea, which were ordered through a retrospective data request, have been received.

The Bering Sea data are from late February and early March. The standing order data are all from the period between 23 March and 20 June 1973. On some days two passes over the Beaufort Sea are available, and for some areas within the Beaufort Sea, cloud-free imagery exists for two or three consecutive days in some of the ERTS cycles.

The overall quality of the data continues to be good. In several of the positive prints, however, dark features are surrounded by an area of anomalously bright tone. This "halo" effect occurs, for example, when an open lead exists in a scene that is otherwise almost completely ice-covered. The effect does not appear to be present in the 70mm negative, so is presumably a result of the "dodged print" processing announced in the ERTS Investigators' Bulletin of 10 April 1973.

2.2 Analysis of Ice Features in ERTS Imagery From Spring 1973

2.2.1 Baffin Bay

During the early spring of 1973, most of the land areas in the Arctic visible in ERTS imagery appear to be surrounded by fast ice. During this season it is often difficult to distinguish the land itself from the fast ice because of extensive snow cover. Moreover, in areas where much open water was observed in the late summer and fall of 1972, compact pack ice (10/10 concentration with no water visible) now exists. Although snow cover also obscures most surface features in the pack ice, the pack ice in most instances can be readily distinguished from the coastal fast ice because of variations in reflectance within the ice field in contrast to the extremely uniform reflectance of the fast ice. In some areas, flaws and flaw leads separate the pack ice from the fast ice.

Imagery covering Baffin Bay on 28 March provides a good example of early spring conditions. The image identifier numbers for the data discussed in this and following sections are given in Table 1. In this imagery, a band of fast ice as much as 25 nmi wide extends along the eastern coast of Baffin Island. The fast-ice boundary is marked by a flaw lead, which is narrow in most areas (about 1/3 - 1/2 nmi wide) but opens to a width of 10 -15 nmi near Henry Kater Peninsula. In the wide portion of the flaw lead, distinct variations in reflectance can be seen, particularly in the MSS-7 band. Along the immediate edge of the fast ice, a narrow band of probable open water exists. Next to the open water is an area of somewhat higher reflectance that is probably representative of newly formed grey ice. Finally an area of higher reflectance, but still not as bright as either the fast ice or the pack ice, can be seen; this area is believed to be somewhat older, grey-white ice. Brighter floes, probably consisting of first-year ice, are embedded in the grey-white ice.

2.2.2 Beaufort Sea

As stated earlier, the great majority of the data received since the winter dark period covers the Beaufort Sea. The individual scenes from selected orbital passes have been mosaiced, so that in some instances the ERTS coverage extends from coastal Alaska to about 80°N. In the mid-Beaufort Sea, because of the lack of landmarks for checking the geographic gridding of the images, ice movement cannot be measured as precisely as it can near coastal areas. However, it is possible to map relative changes in the ice from day to day and over longer time periods, through the repetitive ERTS coverage that occurs at high latitudes. In many of the mosaics, the entire swath is cloud-free; also, ice features can be detected at times through thin cloud cover.

ERTS imagery from several passes during the period from the first of April through mid-June covering the general area of 72-80°N and 126-150°W has been examined. This area contains compact (10/10) and very close (9/10 to less than 10/10) pack ice, but even in the early April data extensive leads can be seen, some being as much as 100 nmi or more in extent. In these early spring images, complex patterns are evident, with newer leads often intersecting older re-frozen leads. As the spring season progresses, the pack ice undergoes deformation from large ice fields into smaller ice floes. Examples of specific features are discussed in the following paragraph.

TABLE 1

ERTS DATE SAMPLE - SPRING 1973

Date	Image Identifier	Geographic Area
24 March	1244-17032 thru 1244-17043	Baffin Bay & Thule, Greenland
25 March	1245-13412 thru 1245-13430	Greenland Sea & E.Coast of Greenland
28 March	1248-15451 thru 1248-15471	Baffin Bay & Baffin Island
1 April	1252-21150 thru 1252-21175	Beaufort Sea
8 April	1259-20130 thru 1259-20151	Prince Patrick Is, Eglinton Is, & Banks Is.
10 April	1261-20241 thru 1261-20264	Prince Patrick Is.&Beaufort Sea
11 April	1262-20295 thru 1262-20320	Prince Patrick Is.&Beaufort Sea
21 April	1272-21255 thru 1272-21285	Beaufort Sea
28 April	1279-20242 thru 1279-20251	Prince Patrick Is.&Beaufort Sea
2 May	1283-20463 thru 1283-20484	Banks Is. & Beaufort Sea
3 May	1284-20521 thru 1284-20535	Beaufort Sea
7 May	1288-21144 thru 1288-21165	Beaufort Sea
17 May	1298-20293 thru 1298-20302	Prince Patrick Is.&Beaufort Sea
20 May	1301-20462 thru 1301-20432	Prince Patrick Is.&Beaufort Sea
6 June	1318-20405 thru 1318-20432	Prince Patrick Is.&Beaufort Sea
10 June	1322-19223 and 1322-19230	Eastern Amundsen Gulf
12 June	1324-19334 thru 1324-19343	Prince of Wales Strait & Amundsen Gulf
13 June	1325-19394	Amundsen Gulf
16 June	1328-19554 thru 1328-19570	M'Clure Strait, Banks Is., & Amundsen Gulf
18 June	1330-21475 thru 1330-21505	Beaufort Sea
18 June	1330-20064 thru 1330-20085	Prince Patrick Is., Eglinton Is., Melville Is., M'Clure Strait, Banks Is., & Beaufort Sea
20 June	1332-20174 thru 1332-20183	Prince Patrick Is., Eglinton Is., M'Clure Strait, Banks Is.

In the imagery of 1 April, a large lead that is about 30 nmi wide at the widest point exists near 74°N, 140°W (see Table 1 for image identifier numbers). As is true with the lead in Baffin Bay, discussed in the previous section, distinct tonal variations are evident within the lead. The differences in tone can be distinguished in both the visible and near-IR spectral bands, and are presumably representative of the gradual re-freezing of the lead through formation of grey and grey-white ice. Twenty days later, on 21 April, the same lead can be seen, although it has narrowed considerably to a maximum width of only 10-12 nmi. On this date, the entire lead appears to contain grey-white ice. Within the grey-white ice small shearing leads are visible; the dark tone of these features indicates either open water or nilas ice. Finally, in an image on 7 May, the lead can barely be distinguished as only a very small difference in reflectance is detectable between the re-frozen lead and surrounding ice.

In the same 1 April mosaic a large lead containing some open water can also be mapped at about 77°. North of the lead the pack ice is essentially solid, whereas south of the lead the ice is intersected with fractures and leads. In the imagery twenty days later, the area north of 77°N has also become fractured; the lead visible on 1 April can no longer be detected.

ERTS data covering the same area on 7 May and 18 June have also been examined. Little change in the general ice structure is evident between 21 April and 7 May, but a significant change appears to have taken place between 7 May and 18 June. By mid-June the entire area, although still consisting mostly of very close pack ice, has broken into ice floes. Moreover, on this date surface features can be detected on the individual floes in the southern part of the Beaufort Sea. In fact, a north to south progression in the visible surface features is noticeable. North of about 80°N, no surface features can be seen; from about 75° to 80°N, some features are visible; south of about 75°N, the ice appears to have deteriorated considerably, with the surface covered by features indicative of rotting ice. On this date, also, a large lead containing open water runs in a northwest-southeast direction near 80°N, 120°W; as was observed in the imagery more than two months earlier in the spring, the lead seems to be a boundary between more solid ice to be north and deformed ice to the south.

2.2.3 Eastern Beaufort Sea - Prince Patrick Island

Ice movement and deformation in the eastern Beaufort Sea near Prince Patrick Island and the mouth of M'Clure Strait can be mapped throughout the spring season through use of ERTS imagery. Early in the spring, in imagery on 8, 10, 11, and 28 April, a quasi-permanent flaw lead can be observed just west of Prince Patrick Island. The lead separates fast ice along the coast and in M'Clure Strait from pack ice to the west. In the April imagery, all land and ice surfaces are snow covered and, therefore, appear smooth.

Significant changes in the configuration of the lead can be mapped from the imagery. On the 8th, the maximum width of the lead is 2 nmi; two days later, it has widened to a width of 6 nmi near Prince Patrick Island and 15 nmi at M'Clure Strait; one day later, on the 11th, the maximum width is as much as 20 nmi. Later in the month the widening continues, so that on 28 April the lead is as much as 30 nmi wide. In addition to widening, shearing of the ice is apparent, with the western edge of the lead having moved southward. Detailed features along the edge can be mapped on the imagery and can be fit exactly with corresponding features on the eastern edge. As the lead opens, new ice formation is also evident. On the 10th and 11th, the low reflectance indicates the formation of grey ice, whereas on the 28th the higher reflectance in the western portion of the lead indicates that much of the ice has become grey-white. On each date the area of new ice formation is along the immediate eastern edge of the lead. Ice floes, judged to be either first-year or multi-year ice because of their high reflectance, are also embedded in the newer ice within the lead.

The same area can be observed again in imagery on 2 and 3 May. During the short interval since the previous observation (28 April), ice conditions have changed dramatically. The lead has now closed in again and is full of ice floes, with very little grey or grey-white ice evident. Changes continue to take place, and by the next ERTS cycle (17 May) the lead has once again reopened in the area south of Prince Patrick Island. In these three observations, the formation of a giant floe (about 95 nmi across) can also be traced. The floe develops from fractures that can be detected on the 2nd and 3rd of May, and can be identified in later data on 20 May and 6 June. By the last date, the floe has become surrounded by a broken ice field containing much smaller floes, and surface features can now be seen on the floe.

2.2.4. Amundsen Gulf and M'Clure Strait

Through repetitive ERTS coverage during mid-June, ice deterioration can be observed in Amundsen Gulf and M'Clure Strait. On 10, 12, and 13 June the eastern part of Amundsen Gulf is observed, and on 16, 18, and 20 June M'Clure Strait is observed. In both areas the ice appears to be in a state of rapid deterioration. The ice surface is covered with various patterns indicative of puddling and thawing, and ice breakup is occurring in Amundsen Gulf and at the western end of M'Clure Strait. Shore polynyas exist along Banks Island, particularly at the mouths of the rivers. In Amundsen Gulf, the movement of ice floes over the 4-day period can be observed. Surface weather charts indicate that temperatures throughout the Canadian Northwest rose well above freezing during the month of June.

2.3 Ice Features Identified in ERTS Imagery in 1972 and 1973

2.3.1. Ice Features, Including an Ice Island, North of M'Clure Strait

ERTS imagery covering M'Clure Strait and northward, including Crozier Channel and the Kellett and Fitzwilliam Straits, on 20 June 1973 can be compared with imagery covering the same area on 28 July 1972. In late July 1972, temperatures in this area had been well above freezing for some time; in 1973, the temperature at Mould Bay on Prince Patrick Island had been above freezing since late May. In general, more surface features seem to be visible on the ice in M'Clure Strait in 1973 than in 1972. To the north, the ice surface is quite similar in the imagery from the two years. At both times, much of the ice has a very low reflectance in the near-IR, indicative of surface melt water. In these areas, however, the ice is intersected by bright linear patterns indicative of ridges, and bright spots indicative of hummocks. In Crozier Channel and Kellett Strait, most of these bright features can be identified in the imagery from 1972 and 1973. In a few places, some changes in the patterns have apparently taken place over the winter.

An interesting ice feature in Moore Bay north of Fitzwilliam Strait can be detected in the imagery from both 1972 and 1973. The feature is a circular area, about 10 nmi across, that appears to be considerably

smoother than the surrounding ice. In the 20 June 1973 image, the circular area is particularly distinct in the near-IR band, as the surrounding ice is marked with puddled areas. The patterns are similar although not quite as distinct a year earlier. It is believed that this feature may be an ice island trapped in Moore Bay.

2.3.2. Melville Bay Icebergs

The area in northern Baffin Bay extending from Melville Bay to Thule, Greenland, is covered in ERTS images on 23 September 1972 and 24 March 1973. Much of the area is ice-free in September, but is completely ice covered in March. Of particular interest are the icebergs that can be identified in many of the fields in this area. In De Dodes Fiord, for example, three icebergs that are trapped in coastal fast ice can be seen in the September and March images. The identification of icebergs can be made because of their shadows on the surrounding sea ice. In order to examine this area more carefully, enlargements of the images have been prepared. In the enlarged prints (scale approximately 1: 200,000), the icebergs can still be detected and appear to have moved very little during the 6-month period. Using the enlargements, measurements will be made to determine the sizes of the icebergs.

In the March image, some icebergs also appear to be detectable in the pack ice of Melville Bay. What are believed to be icebergs are brighter than the surrounding ice, probably because of the reflection off their vertical sides. Also, in several instances, areas of open water exist to the southeast of the icebergs, apparently as a result of the pack ice pulling away under the influence of wind action.

2.3.3. Greenland Sea Iceberg Tongue

A tongue of ice that appears to consist of embedded icebergs can be identified in Dove Bay on the east coast of Greenland (76° - 77°N) in imagery on 25 September 1972 and 25 March 1973. The tongue extends into Dove Bay between Edvards Island and the adjacent island (one of the Godfred Hansens island group), a width of about 3 nmi. Storstrommen, a large glacier, has its mouth in Borge Fiord, just west of Edvards Island. The tongue is believed to consist of numerous icebergs because considerable relief is detectable; the numerous small triangular shadows are characteristic of icebergs. In

September the tongue extends into ice-free water, whereas in March it is surrounded by sea ice. The surrounding ice, however, is smooth, in contrast to the iceberg tongue. In the vicinity of Dove Bay, other areas of icebergs embedded in fast ice can also be detected.

2.4 Comparison Between ERTS Imagery and Aerial Survey Ice Charts

In the previous progress report (Type I report, 24 May), the comparison between ice features mapped from ERTS imagery during the late summer and early fall of 1972 and as depicted on aerial survey ice charts was discussed. In summary, the comparative analysis has shown generally good agreement between the locations of ice edges and ice concentrations as indicated on aerial ice observation charts and as mapped from ERTS imagery. The agreement with two radar ice edges in the Greenland Sea, however, is not as close as is the agreement with most of the ice edges indicated to have been mapped visually. Ice surface features indicated to be ridges and thaw holes are readily detected in the ERTS imagery; hummocks, puddles, frozen puddles, and rafted ice are not as readily detected in the imagery, although brightness variations can be distinguished on some ice surfaces, thereby suggesting their presence. In the ERTS imagery, younger forms of ice (grey-white and grey ice) can usually be distinguished from older ice; the older ice contains brightness variations suggesting the presence of ridges, thaw holes, puddles and hummocks, whereas the younger ice appears much more uniform in reflectance. Areas indicated on ice charts to consist of the darker new or nilas ice appear to be essentially ice-free in the imagery. Also, in areas indicated to consist of mixtures of multi-year, second year, or first year ice, differences in reflectance in the ERTS imagery that could be associated with each ice type are not readily apparent.

Of the three aerial survey charts for this spring received from the Canadian Ice Forecasting Central, only one chart is for an area covered by ERTS imagery on a nearby date. The chart depicts ice conditions in M'Clure Strait and southward along the west coast of Banks Island on 17 June; the corresponding ERTS imagery for the same area is one day later. The comparative analysis indicates that on the ice chart the edge of the fast ice that extends southward from M'Clure Strait along the west coast of Banks Island is shown as being from 5 to 17 nmi farther west than is mapped from the

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ERTS imagery. Also, the ice chart reports the age and concentration of the fast ice in M'Clure Strait and along the west coast of Banks Island as 7/10 multi year ice, 2/10 second year ice, and 1/10 first year ice. The smoother topography of the ice surface and the melt pattern consisting of large interconnecting puddles and a well developed drainage system observed in the ERTS imagery appear to agree with this report in the region of M'Clure Strait; however, the whiter color and distribution of topographic features observed in the fast ice along the west coast of Banks Island appear more indicative of first year ice. ERTS imagery for late September 1972 had shown ice free conditions extending well to the west of Banks Island, whereas very close pack ice comprised of multi year or second year ice floes was observed in M'Clure Strait.

2.5 Bering Sea Experiment (BESEX)

The Bering Sea Experiment (BESEX), a joint effort between the USA and USSR, was conducted during the period from mid-February through early March 1973. The primary area of interest extended southward from St. Lawrence Island to beyond the edge of the pack ice. During the experiment some 14 flights were made by the NASA CV-990 aircraft, operating out of Elmendorf Air Force Base in Anchorage. The targets for the flights were either precipitating cloud profile, ocean roughness, or ice mosaic. One flight, on 3 March, flew north to the Beaufort Sea to overfly the 1972 AIDJEX site. On all flights numerous on-board experiments were conducted including nearby continuous vertical viewing aerial photography.

During the BESEX period ERTS data were collected on a total of four passes over the Bering Sea. On two dates, 27 and 28 February, the ERTS passes crossed the easternmost part of the Bering Sea in the Nunivak Island area (ERTS Identifier Number 1219-21382 through -21391, and 1220-21440 through -21445). On 6 and 7 March, the passes crossed St. Lawrence Island and the prime BESEX area of interest (ERTS Identifier Numbers 1226-22165 through -22185, and 1227-22223 through -22241). The data for each of these four passes have been acquired from the NDPF. For each pass mosaics have been prepared from the MSS-5 and MSS-7 data, and the geographic gridding has been carefully checked using land features as a guide. For selected scenes enlarged prints (scale of 1: 500,000) are being processed.

Through reference to the CV-990 Navigational Flight Data it was possible to plot the segments of the flight paths that crossed the areas of the ERTS images. On 5 March an ice mosaic flight was conducted, and on 7 March an ocean roughness flight took place. Although the first flight was a day earlier than the ERTS data, two segments of the flight path did cross the area of ERTS coverage in the vicinity of St. Lawrence Island. On 7 March, much of the flight path was near the ice edge well south of St. Lawrence, where considerable cloud cover is evident in the ERTS imagery. The final leg of the flight, however, did pass just south of the island in an area that seems to be essentially cloud-free. On 28 February a very small segment of the inbound leg of the flight crossed the area of ERTS coverage near Nunivak Island. On the 27th, the flight path was entirely north and west of the area shown in the ERTS imagery. For all appropriate cloud-free segments of the flights, copies of the vertical-viewing photography (5 inch x 5 inch) have been requested from NASA/GSFC.

In the ERTS imagery of 6 March an area of low reflectance, apparently grey ice, extends southward from St. Lawrence Island. Along the immediate south coast of the island, a band of apparent open water exists. Over the open water small streaks of stratus cloud can be seen; the ice to the south, however, appears to be cloud-free. To the north and to the southeast of St. Lawrence brighter ice floes exist, surrounded by the grey ice. Numerous fractures and leads cut through the bright (first year and multi-year) ice and the surrounding grey ice. Differences between the apparent grey ice and the older ice are especially noticeable in the MSS-7 imagery.

The commentary by the ice observer onboard the CV-990, given in the Navigational Flight Data report, is in remarkably good agreement with the ice conditions deduced from the ERTS data, even though the flight is a day earlier. To the north of St. Lawrence the observer reports generally 80% first-year and multi-year ice and 20% grey ice. Where the observer reports simple shearing leads, leads are detectable in the imagery. Also, the north coast of the island is reported as having heavily compacted ice; in the imagery, the ice in that area does appear solid, quite different from the ice south of the island.

As the flight approaches the western end of St. Lawrence Island the commentary indicates that the amount of first-year and multi-year ice is decreasing and that the ice ahead is mostly grey ice; the location of the

ice boundary separating these different ice types in the ERTS imagery corresponds almost exactly with the location when the above comment was made. After crossing the island, the observer reports all grey ice a few days old, some of which has undergone deformation in the form of stretching to the southwest. This observation confirms the ice type deduced from the ERTS data; furthermore, leads indicative of stretching of the ice can be seen in the imagery.

The ice conditions displayed in the ERTS imagery on 7 March are very similar to those of the previous day. On the 7th, however, the stratus streaks have increased, obscuring some of the grey ice south of St. Lawrence Island. Farther south some ice features can be detected, but much cloudiness exists. One segment of the CV-990 flight on this day follows the southern boundary of the grey ice, an area that is cloud-free. The observer reports a vast expanse of grey ice, and then reports running into a stratus deck; the comment is made that the "stratus streaks are due to open water along the south shore of St. Lawrence". Thus, this commentary verifies exactly the ice and cloud conditions apparent in the ERTS imagery.

On 28 February, although only a small segment of the flight crosses the area of ERTS coverage, open water can be detected in an area where the observer reports a shore polynya. The observer also reports grey ice in the polynya, which is evident also in the ERTS data. The grey ice has a higher reflectance in the MSS-4 than in the MSS-7 imagery; however, near Nunivak Island the distinction between grey and grey-white ice is much better defined in MSS-7 than in the visible band.

Some ice movement can be mapped by comparing the 28 February imagery with that of the previous day. It appears that the grey-white ice (and some of the 1st year ice floes) has moved farther off-shore during the one-day interval. The ice edge does not change its position, however. The ice edge consists of numerous ice belts that appear very bright in both the MSS-5 and MSS-7 imagery. The ice belts likely result from wind and wave action.

2.6 Practical Applications and Estimates of Costs and Benefits Resulting From the Use of ERTS Data for Mapping Sea Ice

The principal agencies responsible for ice reconnaisance in the Arctic

are the Ice Forecast Office of the U.S. Navy Fleet Weather Central and the Canadian Ice Forecasting Central. The directors of these agencies, Commander William Dehn of the Navy Ice Forecast Office and Mr. William E. Markham of the Canadian Ice Forecasting Central, have expressed considerable interest in the progress of the investigation to map sea ice using ERTS data. At the invitation of Commander Dehn, Mr. Clinton J. Bowley, of ERT, attended the Navy Ice Observer Course to gain a better understanding of the procedures used on ice reconnaissance flights to identify ice types. The directors of the two agencies have also provided aerial survey ice charts and helpful suggestions for interpreting various ice features in the ERTS imagery.

Both Commander Dehn and Mr. Markham have spoken enthusiastically of the potential practical applications of ERTS with regard to mapping arctic ice. In fact in a recent communication from the Canadian Ice Forecasting Central, Mr. Markham states that he believes that the "quick-look" ERTS data--black and white product only--could replace the April ice survey flights at a considerable saving in cost. He states further that because of the high frequency of cloud-free conditions in the Arctic at that time of year, he expects the concept to be valid and may be pursued in the future.

3. NEW TECHNOLOGY

No new technology has been developed during this reporting period of the subject contract.

4. PROGRAM FOR NEXT REPORTING PERIOD

During the next reporting period the investigation of the application of ERTS data for mapping arctic sea ice will be concluded. Analysis of the data sample from the 1973 spring and early summer season will be completed, and further measurements of the scales of identifiable ice features, the movements of ice, and the ice deformation will be made. Meteorological charts will be consulted to determine relationships between ice deformation and movement and the prevailing wind conditions.

Further investigation of the ice types identifiable in ERTS imagery will be conducted using additional aerial ice survey charts from the early summer and aerial photography from the Bering Sea Experiment. It is anticipated that the aerial photography will be especially useful for determining the scale of the ice features that can be mapped at the resolution of the ERTS data. At the conclusion of the study, a final report detailing all analysis procedures, results, and conclusions will be prepared.

5. CONCLUSIONS

The results of the analysis of data collected during the spring of this year demonstrate that ERTS imagery has a high potential for monitoring arctic sea ice conditions during the time of maximum ice extent and the beginning of the ice-breakup season. In the eastern Beaufort Sea area, the combination of ERTS orbital overlap and a high incidence of cloud-free conditions during the spring assures a high frequency of repetitive satellite coverage. With this repetitive coverage, the deformation and movement of ice features can be mapped throughout the early April to late June period.

In the mid-Beaufort Sea, numerous fractures and leads can be identified, even in the early spring data. In the easternmost Beaufort Sea, near Prince Patrick and Banks Islands, a quasi-permanent lead can be identified over an extended period, and the growth and eventual deterioration of the lead can be mapped. Ice features that can be identified include the following: the development of fractures leading to the formation of distinct ice floes; the growth and deterioration of leads; evidence of shearing movements of ice masses; the formation of new grey ice within leads; the distinction between grey, grey-white, and older forms of ice; and the deterioration of the ice surface evidenced by the formation of puddles, thawholes, and drainage patterns. As was found in analyses performed earlier in the study, ice types can be identified most reliably through analysis of both the visible and near-IR spectral bands.

A comparative analysis of ERTS data collected during the spring of 1973 and during the late summer and early fall of 1972 shows both similarities and differences in the ice conditions. The ice in M'Clure Strait in late June appears to have more surface features than were detectable in late July of the previous year. To the north of M'Clure Strait, ridges and hummocks mapped from imagery of last summer can again be identified in the imagery from this June. An interesting circular feature off the northeast coast of Prince Patrick Island, which is believed to be an ice island, can also be identified. In the eastern Arctic, icebergs trapped in fast ice in Melville Bay, first detected in imagery from September, can again be identified in imagery from this March. Similarly, an iceberg tongue extending into Dove Bay on the east coast of Greenland can be detected in images from before and after the winter dark period.

Data from ERTS passes crossing the Bering Sea in early March have been correlated with ice observations collected in the Bering Sea Experiment (BESEX). On two flights of the NASA CV-990 aircraft, the ice conditions in the vicinity of St. Lawrence Island reported by the onboard observer are in remarkably close agreement with the ice conditions mapped from the corresponding ERTS imagery. The ice features identified in ERTS imagery and substantiated by the aerial observer include the locations of boundaries between areas consisting of mostly grey ice and of mostly first and multi-year ice, the existence of shearing leads, and the occurence of open water with the associated development of stratus cloud streaks. The BESEX correlative ice information verifies the potential of practical applications of ERTS data. The potential is so great, in fact, that the concept of using ERTS data to replace the April ice survey flights at a considerable saving in cost is being contemplated by the Canadian Ice Forecasting Central.

6. RECOMMENDATIONS

Specific recommendations will be included in the final report to be prepared during the next reporting period.